BEYOND THE NUMBERS RESEARCH SERIES

THE MUSIC WITHIN

Genetics, Development, Culture, and the Human Connection to Music

A long-form evidence-balanced research project

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Abstract

Background: Music appears early, clusters in families, and affects perception, movement, emotion, memory, and social behavior, yet public claims often collapse genetic influence, training, culture, and clinical benefit into a single idea of musical power.

Objective: To synthesize evidence on the inheritance and development of component musical traits, music's effects across the life span, cultural and technological mediation, and condition-specific therapeutic uses and harms.

Methods: Narrative review of peer-reviewed reviews, meta-analyses, genetically informative studies, developmental experiments, cross-cultural research, and clinical evidence identified through structured searches described below. Claims were graded by design quality, consistency, directness, and practical relevance.

Results: Evidence supports genetic influence on several component traits, prenatal and infant learning of patterned sound, culture-dependent musical grammars, training-related change in practiced systems, and targeted therapeutic uses. Evidence is weaker for broad cognitive enhancement, prenatal intelligence claims, disease modification, and individual genetic prediction. Music can regulate emotion, coordinate movement, evoke autobiographical memory, and support social interaction, but it can also damage hearing, disrupt sleep, trigger distress, or add no benefit.

Conclusions: Musicality is a profile of partly distinct perceptual, motor, cognitive, motivational, emotional, and social capacities. Biological predispositions shape

experience, experience modifies developing systems, and culture organizes what capacities mean. Inheritance is not destiny, practice is not a guarantee, and meaningful benefit is not the same as cure.

Reader's Guide

Each chapter separates the central finding from its strongest limitation. Citations are author-date references to the complete list at the end. Evidence labels are a synthesis of design quality, consistency, directness, and practical relevance; they are not a formal clinical guideline grade.

Label	Meaning
High	Consistent evidence with direct measures and credible designs.
Moderate	Generally supportive evidence with important design or generalization limits.
Emerging	Promising but limited, heterogeneous, or not yet replicated broadly.
Mixed	Positive and null findings depend strongly on methods or populations.
Unsupported	Popular claim exceeds the available evidence.

Executive Summary

- There is no single musicality trait and no single music gene. Pitch, beat, memory, motor timing, reward, creativity, motivation, and social participation are partly separable.
- Twin and genomic research supports genetic contributions to component traits, but heritability is population-specific and cannot determine an individual destiny.
- Families transmit culture and opportunity together with genes. Instruments, lessons, identity, money, time, and expectations can mimic or magnify inheritance.
- Prenatal and newborn research supports memory for repeated sounds, not claims that prenatal playlists raise intelligence.
- Music training reliably improves musical skills. Far transfer to intelligence or broad academic achievement is small, mixed, or absent in stronger designs.
- Music organizes prediction, emotion, memory, movement, and social timing through distributed networks rather than a single brain center.
- Culture shapes meter, tonality, consonance, emotional meaning, and the definition of music itself; universal and learned components coexist.
- Music-based clinical interventions can help specific outcomes, especially when mechanism and target align, but should be adjunctive, personalized, and honestly graded.
- Unsafe listening is a large public-health risk. Preference does not prevent hearing damage, sleep disruption, trauma triggers, or overstimulation.
- Recommendation systems and generative AI now participate in musical development, exposure, labor, and cultural visibility.

Bottom line The most defensible account is neither “born musical” nor “made musical.” Musical lives emerge from feedback among predisposition, development, opportunity, practice, culture, technology, and meaning.

Methods and Evidence Rules

Design and search date. This project is a structured narrative evidence synthesis, not a de novo systematic review or meta-analysis. Searches were conducted and updated through August 20, 2026. The evidence base was mapped before drafting so that supportive, null, and contradictory findings could be incorporated into the same claim structure.

Information sources and search strategy. PubMed/MEDLINE, PubMed Central, Crossref-linked journal pages, Cochrane reviews, and reference lists of major reviews were searched using combinations of: music, musicality, rhythm, or singing; genetics, heritability, twin, or genome-wide; fetal, prenatal, infant, or development; training, transfer, executive function, or literacy; emotion, reward, memory, or synchrony; therapy, intervention, dementia, stroke, or Parkinson; culture or cross-cultural; hearing or unsafe listening; and recommender systems, streaming, or artificial intelligence. Stable PubMed, PMC, journal, or DOI links were retained in the references.

Eligibility. Included sources were English-language peer-reviewed human research, systematic or narrative reviews useful for mechanism, meta-analyses, genetically informative studies, cross-cultural studies, and clinical reviews directly addressing a chapter claim. Priority was given to larger samples, active comparisons, preregistration, longitudinal or genetically informative designs, and clinically meaningful outcomes. Commercial claims, testimonials, unsourced media summaries, and animal-only evidence were excluded as evidentiary anchors.

Synthesis. Sources were grouped by claim. Confidence was judged from convergence, design strength, directness, precision, replication, and susceptibility to selection, expectancy, cultural bias, or publication bias. No pooled estimate was calculated by the author, and the confidence labels are not formal clinical-guideline grades.

Causal language is restricted. Observational comparisons are described as associations. Brain differences are not treated as proof of benefit or training effects. Heritability estimates are not translated into individual percentages. Clinical findings are stated by intervention and outcome rather than generalized to "music therapy." Null results, heterogeneity, selection, expectancy, socioeconomic confounding, cultural bias, and publication bias are incorporated into conclusions rather than isolated at the end.

Question	Required check
Claim	What trait, exposure, outcome, population, direction, and duration?
Design	Twin, longitudinal, randomized, active-control, imaging, survey, or case evidence?
Alternative	Selection, resources, expectancy, culture, measurement, regression, or chance?
Magnitude	How large, durable, and practically meaningful is the result?
Boundary	What must the reader not conclude?

Review limitations

The search was structured but was not independently duplicated, registered, or accompanied by a PRISMA flow diagram; this paper is therefore a scholarly narrative review, not a systematic review. One author conducted selection and synthesis, increasing the risk of judgment bias. The review spans disciplines with incompatible measures. Several fields change quickly, particularly molecular genetics, generative AI, and clinical evidence. Independent reviewers should test source completeness, claim coding, and confidence assignments.

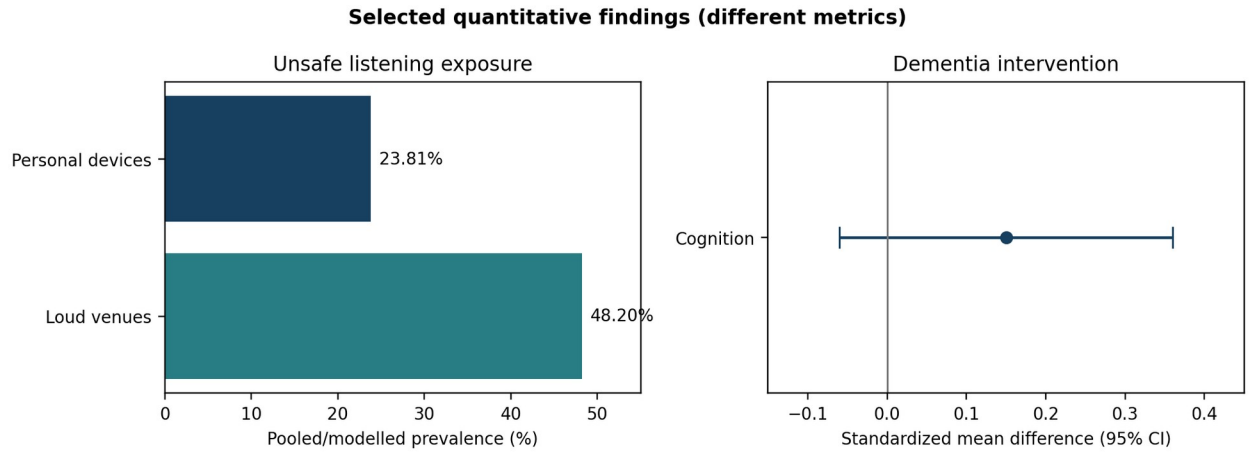

Figure 1. Selected quantitative findings reported by Dillard et al. (2022) and van der Steen et al. (2018). Panels use different metrics.

1. Before the First Note

Music begins before anyone calls it music. A fetus hears a filtered world of pulse, voice, and low-frequency sound; a newborn prefers familiar speech patterns; an infant is calmed or excited by a caregiver's singing long before understanding lyrics. These facts do not prove that a finished musical system is present at birth. They show that human development starts with equipment for detecting timing, contour, repetition, and socially important sound. Musical life grows from those capacities, but it grows inside relationships and cultures that decide which sounds matter.

The central mistake in arguments about musical inheritance is to demand a choice between nature and nurture. The evidence instead describes transactions. Biological differences can influence what a person notices, enjoys, practices, or avoids. Families transmit genes, but also instruments, playlists, expectations, money, time, language, religion, and stories about who is 'the musical one.' Practice changes auditory and motor systems, while early aptitude can make practice more rewarding. Cause runs in both directions.

This paper therefore asks a narrower and more useful question than whether music is genetic: which component capacities show genetic influence, how are they expressed through development, and what does music then do in a life? It treats musicality as a bundle rather than a single score. Pitch, beat, auditory memory, motor timing, reward, improvisation, persistence, and social participation can separate. A person may sing inaccurately yet move precisely, recognize structure without enjoying it, or love music without formal skill. The title, The Music Within,

refers not to a hidden gene but to a developing system built by biology, experience, culture, and meaning. (Wesseldijk & Ullén, 2023; Trehub et al., 2015)

Key distinctions: capacity vs. finished system • inheritance vs. destiny • recognition vs. enhancement

2. What Counts as Musicality?

Everyday speech compresses many abilities into the word talent. Scientific work must unpack it. Perceptual musicality includes discrimination of pitch, contour, timbre, meter, and timing. Productive musicality includes vocal control, instrumental coordination, expressive timing, improvisation, and ensemble synchronization. Motivation, reward sensitivity, working memory, sustained attention, and willingness to practice influence performance but are not identical to auditory aptitude. Cultural knowledge determines whether a performance is recognized as expert in the first place.

Measurement changes the answer. A test based on Western equal temperament or staff notation can reward exposure to one tradition while misclassifying a capable participant from another. Formal lesson history is not a neutral index of ability because lessons depend on family resources and school access. Self-report can capture engagement but is vulnerable to identity and confidence. Laboratory tasks isolate mechanisms but may remove the social and embodied functions that make music important. No single measure can stand for the whole construct.

The most defensible approach is a profile: several component tasks, training and exposure history, cultural context, hearing status, and meaningful participation.

This matters for genetics because a heritability estimate belongs to the measured trait in a particular population, not to 'music' in the abstract. It matters for education because a child who does not match one narrow test may still possess rhythmic, creative, social, or production strengths. It matters clinically because a rhythmic cue for gait is different from a familiar song used for connection. Precision about the outcome is the first protection against exaggerated claims. (Gingras et al., 2015; Singh & Mehr, 2023)

Key distinctions: association vs. causation • mechanism vs. metaphor • group average vs. individual response

3. A Musical Species

Song and organized sound occur in every known human society, but universality does not require identical scales, harmonies, instruments, or definitions. Some traditions separate song from speech less sharply than Western institutions do. A call to prayer may be aesthetically organized yet not categorized by participants as music. Work songs, lullabies, lament, dance, ritual, and coordinated movement reveal recurring functions: regulating arousal, marking group identity, transmitting memory, and aligning bodies in time.

Evolutionary explanations remain plural. Music may have supported caregiver-infant communication, coalition signaling, courtship, coordinated action, or cultural learning. It may also recruit capacities that evolved for other purposes, including auditory scene analysis, prediction, vocal communication, and movement. These accounts are not mutually exclusive, and present-day usefulness

does not by itself identify an original adaptation. The strongest evidence establishes that humans readily learn patterned sound and use it socially; it does not settle one evolutionary story.

Cross-cultural research finds both commonality and variation. Tempo, loudness, roughness, contour, and vocal style can communicate broad information across unfamiliar traditions, while harmony, consonance, meter, and emotional categories are strongly shaped by exposure. Large cross-cultural studies show that mental representations of rhythm are neither wholly universal nor arbitrary. The responsible conclusion is layered: shared perceptual constraints interact with learned musical grammars. Calling music a universal language is poetic, but scientifically it hides the translation work performed by culture. (Trehub et al., 2015; Jacoby et al., 2020, 2024; Athanasopoulos et al., 2021)

Key distinctions: association vs. causation • mechanism vs. metaphor • group average vs. individual response

4. What Families Pass Down

A family resemblance is the beginning of an investigation, not its conclusion. Relatives share DNA, but they also share soundscapes, values, opportunities, and labels. A child in a performing family may hear more complex material, receive earlier correction, have instruments within reach, and view practice as normal. Adults may notice and reward behavior that resembles family identity. These processes can create continuity across generations even when no genetic difference is involved.

The reverse error is to assume that environment cancels biology. Behavioral-genetic studies indicate that several music-related traits, including aspects of pitch perception, rhythm, achievement, and practice behavior, show heritable variation. Heritable does not mean fixed, inevitable, or caused by one gene. It means that, under the conditions sampled, genetic differences statistically account for part of the variation among people. Change the range of instruction or inequality and the estimate can change.

Families also illustrate gene-environment correlation. Parents provide environments partly related to their own dispositions; children evoke responses based on early behavior; and older children select activities that fit their interests. A child with slightly better timing may enjoy ensemble success, receive praise, practice more, and become far more skilled. Another with equal potential but poor access may never enter the loop. What looks like a straight line from parent to child is better understood as feedback among predisposition, opportunity, identity, and accumulated experience. (Wesseldijk & Ullén, 2023; Mosing et al., 2014)

Key distinctions: genetic transmission vs. cultural transmission • family resemblance vs. causal mechanism

5. Twins, Heritability, and Prediction

Twin designs compare resemblance among identical twins, who share nearly all segregating DNA, with fraternal twins, who share on average about half. When identical twins are more similar on a measured trait, genetic influence is one plausible explanation. These designs have helped establish that music-related

variation is not purely instructional. They also estimate shared and nonshared environmental contributions, although those categories are statistical, not simple lists of experiences.

Important assumptions remain. Identical twins may be treated more similarly, choose more similar environments, or reinforce a shared identity. Measures can favor trained participants. Samples often come from affluent Western populations with restricted ranges of deprivation and cultural exposure. Heritability is a property of variation in a population at a time; it cannot tell an individual what percentage of an ability came from genes. A highly heritable trait may still respond to training, and a low estimate does not make biology irrelevant.

Prediction is even harder. Complex traits are influenced by many variants of very small effect, interacting with development and environment. A polygenic association useful at the group level may perform poorly for one person or another ancestry group. Genetic screening for musical potential would therefore be scientifically premature and ethically dangerous. The proper value of genetically informative research is explanatory: it warns that selection into practice and training is not random, clarifies individual differences, and improves study design. It should not become a gatekeeping device for children. (Wesseldijk & Ullén, 2023; Mosing et al., 2014)

Evidence posture: Moderate confidence. Interpretation depends on the measured component, population, comparator, and duration; broad slogans are less defensible than specific claims.

Key distinctions: heritability vs. immutability • population estimate vs. individual prediction

6. From Genes to Component Traits

Molecular research has moved from small candidate-gene reports toward genome-wide methods. Early studies sometimes attached large stories to a few biological pathways, but complex behavioral traits rarely submit to that simplicity. Current evidence supports highly polygenic influence: many variants, each contributing a tiny amount, operating through hearing, neural development, timing, memory, motor control, personality, reward, and learning. Replication and diverse samples are essential.

Selective conditions help reveal separable components. Congenital amusia can impair fine-grained pitch processing or melodic organization despite typical intelligence and ordinary hearing. Beat deafness can affect synchronization without eliminating musical interest. Specific musical anhedonia describes low pleasure from music despite normal reward responses in other domains. Absolute pitch depends on early learning and cultural conditions as well as individual predisposition; it is not a universal summit of musicianship.

The emerging picture resembles a mixing board rather than a switch. Component settings differ, compensate, and interact. Strong auditory memory may help a performer with average pitch precision; exceptional timing may support ensemble

skill; motivation can multiply modest early advantages. This architecture explains why family members can resemble one another without matching and why expertise has many routes. Genetic findings are most informative when linked to clearly measured components and least informative when marketed as a score for 'talent.' (Gingras et al., 2015; Martínez-Molina et al., 2016; Wesseldijk & Ullén, 2023)

Key distinctions: association vs. causation • mechanism vs. metaphor • group average vs. individual response

7. Gene-Environment Interplay

Practice changes performance, but people do not receive or choose practice randomly. In a large twin study, music practice itself showed substantial heritability, and the association between practice and ability was largely explained by shared genetic factors. The provocative title 'practice does not make perfect' should not be misread as saying practice has no value. It means that hours alone did not operate as an isolated causal dose in that sample and that predispositions influenced both practicing and performance.

Training effects are shaped by quality, feedback, rest, goals, and the fit between learner and method. Deliberate practice can refine auditory categories, motor programs, error detection, expressive control, and ensemble prediction. Yet identical hours can produce different results, and retrospective practice estimates are noisy. Motivation, health, anxiety, family support, teacher quality, and access affect persistence. Dropout is data, not merely failure.

A transactional model resolves the false argument between gift and work. Early differences influence experience; experience magnifies, redirects, or compensates for differences; success changes identity; identity changes effort and social opportunity. Sensitive periods may make some learning easier, especially accent-like auditory categories and absolute pitch, but they are not universal expiration dates. Late beginners can develop meaningful, sophisticated musicianship. The practical implication is broad access plus responsive instruction, not biological sorting or the promise that effort guarantees identical outcomes. (Mosing et al., 2014; Wang & Zhang, 2022)

Key distinctions: association vs. causation • mechanism vs. metaphor • group average vs. individual response

8. Music Before Birth

By late gestation, the fetus receives a low-pass version of the outside world together with maternal voice, heartbeat, breathing, and movement. Research supports fetal learning of repeated auditory patterns and newborn responses to familiar speech or melodies. A 2023 systematic review found evidence for stimulus-specific memory traces but also substantial differences in exposure type, intensity, duration, outcome measures, and study quality. Recognition is not the same as enhanced intelligence.

Prenatal claims are especially vulnerable to commercialization. Parents are told that particular music can mature the brain, increase creativity, or improve later achievement. The evidence does not justify those promises. Short-term changes in

heart rate, orientation, habituation, or neonatal behavior do not establish durable cognitive advantage. Maternal relaxation, routine, and voice may be as important as the musical content, and poorly controlled studies cannot separate these pathways.

Safety and relationship provide the appropriate frame. Ordinary singing and comfortable listening can be part of prenatal life without turning pregnancy into a training program. Sound delivered close to the abdomen or at high intensity is not automatically benign; the fetal auditory system is developing, and exposure should not exceed established safety guidance. The strongest conclusion is modest but meaningful: prenatal experience can create memory for sound and prepare continuity with the postnatal social world. It is not prenatal tutoring. (Ullal-Gupta et al., 2013; Chorna et al., 2019; Movalled et al., 2023)

Evidence posture: Moderate confidence. Interpretation depends on the measured component, population, comparator, and duration; broad slogans are less defensible than specific claims.

Key distinctions: fetal learning vs. prenatal intelligence • ordinary listening vs. directed sound exposure

9. Infancy: Rhythm, Voice, and Bonding

Infant-directed song exaggerates pitch contour, timing, repetition, and emotional expression. Caregivers use it to attract attention, soothe, play, and coordinate routines. Infants do not passively receive a soundtrack; gaze, movement, vocalization, and arousal shape the caregiver's next phrase. The interaction is a feedback system in which musical structure makes social timing predictable.

Research on caregiver-infant musical interaction supports roles in co-regulation, mutual engagement, and affiliation. Studies show that the rhythm of singing can entrain infants' visual attention and that familiar songs organize expectations. These findings do not mean that singing guarantees secure attachment or accelerates every developmental domain. The relevant unit is often the responsive relationship, with music serving as a structured medium.

Cultural variation begins immediately. Lullabies share recurring features across societies, yet scales, vocal timbres, movement, and caregiving arrangements differ. Infants learn the statistical regularities surrounding them and gradually narrow expectations toward familiar meters and tonal patterns. Early openness followed by experience-dependent specialization parallels language development. The policy implication is not a standardized infant playlist; it is support for responsive caregiving, cultural continuity, and opportunities for families to make music together without performance pressure. (Lense et al., 2022; Nguyen et al., 2023; Trehub et al., 2015)

Key distinctions: association vs. causation • mechanism vs. metaphor • group average vs. individual response

10. Childhood and Learning

Music lessons combine attention, memory, perception, motor planning, feedback, and emotion. Children learn to predict, detect error, inhibit a premature response, coordinate with others, and sustain effort. Because training is cognitively rich,

researchers have asked whether benefits transfer beyond music to language, executive function, literacy, mathematics, and general intelligence.

The evidence is mixed and depends strongly on design. Observational comparisons often find that musically trained children perform better, but families selecting lessons differ in income, education, expectations, and prior ability. Randomized and active-control studies usually produce smaller effects. A major meta-analysis concluded that broad cognitive and academic benefits became small or null in higher-quality designs, while newer meta-analyses report modest gains in executive function. Near transfer to closely related auditory skills is more credible than far transfer to general intelligence.

The case for music education does not require an IQ effect. Music is a form of knowledge, expression, community participation, and disciplined craft. Programs can strengthen belonging, listening, collaboration, and access to cultural inheritance even when standardized test scores do not move. The correct educational promise is that children can learn music and may gain specific related skills—not that arts funding must justify itself as a hidden mathematics intervention. (Sala & Gobet, 2020; Gordon et al., 2015; Cai & Kang, 2025)

Evidence posture: Mixed confidence. Interpretation depends on the measured component, population, comparator, and duration; broad slogans are less defensible than specific claims.

Key distinctions: musical learning vs. far cognitive transfer • arts value vs. test-score justification

11. Adolescence: Identity Turned Up

Adolescence intensifies music's personal and social functions. Young people use songs to name emotions, claim autonomy, affiliate with peers, explore values, and distinguish themselves from adults or rival groups. A playlist can operate as a diary, badge, coping tool, and map of belonging. These uses make preference feel deeply personal even though it is continuously shaped by peers, platforms, family history, and marketing.

Listening is the most commonly studied musical activity for emotion regulation. It can increase energy, permit catharsis, support reflection, distract from distress, or deepen a desired mood. Regulation is not automatically healthy. Repetitive sad music may validate and organize emotion for one listener while reinforcing rumination for another. Context, intention, personality, and mental state determine whether the same track helps, does nothing, or worsens distress.

Moral panics about genres and lyrics often confuse correlation with causation. Young people drawn to aggressive or despairing content may already be responding to social experience. Experimental effects are usually smaller and more conditional than public arguments suggest. The more immediate risks include unsafe volume, sleep disruption, harassment within scenes, and algorithmic reinforcement. Respectful adult engagement is more informative than condemning a genre. (Saarikallio et al., 2020; Chong et al., 2024; Chen et al., 2023)

Key distinctions: association vs. causation • mechanism vs. metaphor • group average vs. individual response

12. Adulthood, Aging, and Autobiographical Memory

In adulthood, music becomes an archive of episodes and identities. A few seconds can reinstate a room, relationship, loss, celebration, or former self. Music-evoked autobiographical memories are often vivid and emotional because songs are repeated across personally important periods and bind sensory, social, and narrative information. Familiarity and self-selection therefore matter more than a generic category such as 'relaxing music.'

In later life, singing and listening can support social connection, mood, movement, and access to personal memory. People living with dementia may respond to familiar music even when other forms of communication are impaired. These moments can be clinically and humanly meaningful, but they should not be described as reversal of neurodegeneration. Reviews find benefits for some behavioral and emotional outcomes with substantial heterogeneity in interventions and study quality.

Aging also changes the listening body. Hearing loss, tinnitus, sensory sensitivity, medication, fatigue, and cognitive load affect benefit and risk. Programs should be personalized, consent-based, and evaluated for real outcomes such as distress, engagement, caregiver interaction, gait, or quality of life. Preserved response to music demonstrates distributed and resilient systems; it does not establish a miracle exception to disease. (van der Steen et al., 2017; Raglio et al., 2015)

Evidence posture: Moderate confidence. Interpretation depends on the measured component, population, comparator, and duration; broad slogans are less defensible than specific claims.

Key distinctions: association vs. causation • mechanism vs. metaphor • group average vs. individual response

13. The Predictive Musical Brain

Music unfolds through time, forcing the brain to predict what may happen next. Meter creates expectations about when; tonal and melodic structure create expectations about what; timbre and performance style signal who or how. Pleasure often emerges between confirmation and surprise. Perfect predictability becomes dull, while total unpredictability becomes difficult to organize. Groove, tension, release, and expressive timing exploit this middle ground.

No single music center exists. Auditory cortices analyze sound; motor and cerebellar systems track timing and simulate movement; memory systems compare patterns; attention selects events; reward systems assign value; and social cognition interprets intention. Training can change structure and function in parts of this network, but cross-sectional musician/nonmusician differences do not prove that lessons caused every difference. Selection into training remains a competing explanation.

Brain images are especially easy to oversell. Activation means that a region participates under a contrast, not that it contains an emotion or has been upgraded. Greater activation is not always better, and reduced activation can reflect efficiency. Neuroplasticity is a property of learning, including maladaptive

learning. The strongest neuroscience explains mechanisms that connect to behavior; it does not replace behavioral evidence with colorful pictures. (Wan & Schlaug, 2010; Reybrouck et al., 2022)

Key distinctions: association vs. causation • mechanism vs. metaphor • group average vs. individual response

14. Why Music Moves Us

Music can produce chills, tears, calm, energy, tenderness, grief, and awe without an external event corresponding to the emotion. Reward research implicates interactions among auditory prediction, memory, and mesolimbic systems. Anticipation and peak pleasure can recruit partly different moments of the reward process. Personal familiarity and meaning strongly alter response, which is why a laboratory excerpt may underestimate or distort everyday experience.

Sad music reveals the difference between perceived and felt emotion. Listeners may appreciate beauty, empathy, nostalgia, emotional rehearsal, or the safe containment of sadness. Pleasure does not require becoming simply happy. Likewise, energetic music can be enjoyed without aggression. Emotional response combines acoustic cues, learned conventions, current mood, memory, social setting, and purpose.

Individual differences set important limits. People with specific musical anhedonia perceive music but experience little reward, associated with altered interaction between auditory and reward networks. Others experience intense chills; many respond moderately. This variation refutes claims that one playlist is universally

therapeutic. It also supports the project's central model: perceptual capacity, reward sensitivity, learning, identity, and context are partly separable layers. (Sachs et al., 2015; Martínez-Molina et al., 2016; Loui et al., 2017)

Key distinctions: association vs. causation • mechanism vs. metaphor • group average vs. individual response

15. Music, Memory, and Language

Music and language both organize sound hierarchically, depend on timing and prediction, and use prosody to convey information. They share resources without being the same system. Melody can support recall by chunking material and providing redundant cues; rhythm can organize attention; singing exaggerates pitch and timing. These features explain why songs are effective carriers of cultural memory and why lyrics can remain accessible when ordinary recall is difficult.

Claims about literacy and language transfer require design discipline. Meta-analytic evidence suggests possible benefits for phonological awareness and closely related auditory skills, but effects on reading fluency and broader achievement vary with controls and study quality. Musically trained families may also provide enriched language environments. Training that explicitly connects rhythm, pitch, and speech is more likely to show near transfer than an unrelated lesson expected to improve all language.

Memory has costs as well as benefits. Involuntary musical imagery, or earworms, is common and usually neutral or pleasant, but it can capture attention, interfere

with sleep, or become distressing. Musical hallucinations and obsessive phenomena are clinically distinct from ordinary inner repetition. The same predictability and repetition that make songs memorable can make them hard to dismiss. (Gordon et al., 2015; Liikkanen & Jakubowski, 2020; Scullin et al., 2021)

Key distinctions: association vs. causation • mechanism vs. metaphor • group average vs. individual response

16. Bodies in Time

Listening is bodily even when the listener is still. Beat perception recruits motor prediction; people tap, sway, dance, breathe, work, march, and exercise in time. Synchronization reduces uncertainty about others and can increase affiliation. Group movement has been associated with bonding even across group divides, though synchrony can also strengthen conformity and in-group boundaries.

Clinical rhythm applications are strongest when the mechanism and target are specific. Rhythmic auditory stimulation can provide external timing cues for gait in Parkinson's disease or after neurological injury. Music-supported therapy can structure repeated upper-limb movement after stroke. These approaches do not work because music is magical; they exploit coupling among auditory timing, prediction, and motor systems.

Outcomes depend on tempo matching, impairment, therapist skill, dosage, and transfer outside treatment. A laboratory improvement in synchronized steps is not automatically fewer falls or independent mobility. Music may add motivation and adherence, but an enjoyable intervention can still be ineffective on the primary

outcome. Clinical claims should state whether the intervention is rhythmic cueing, instrument playing, singing, or listening, because pooling them under 'music therapy' hides mechanisms. (Janzen et al., 2022; Xu et al., 2022)

Evidence posture: Moderate confidence. Interpretation depends on the measured component, population, comparator, and duration; broad slogans are less defensible than specific claims.

Key distinctions: association vs. causation • mechanism vs. metaphor • group average vs. individual response

17. Culture Teaches the Ear

Listeners acquire musical grammars through exposure, usually without explicit instruction. Repeated patterns create expectations about scale, meter, phrase, ornament, timbre, and emotional meaning. Western listeners commonly associate major with happiness and minor with sadness, but cross-cultural work shows that this mapping is not a universal law. Tempo, register, intensity, and roughness may travel more readily than harmonic conventions.

Research design can manufacture cultural difference or erase it. Tasks translated literally may remain conceptually foreign; rating scales may assume that emotion is an individual internal state rather than a social or spiritual event. Recorded excerpts remove dance, ritual, place, and participation. Conversely, global media makes it difficult to find participants truly unfamiliar with Western music. Good cross-cultural science collaborates with communities and tests whether constructs are locally meaningful.

Culture is not noise to be controlled away. It is part of the causal system through which sound becomes music. Biology constrains what ears and brains can process, while culture organizes attention and value inside those constraints. Universalism without culture becomes reductionist; cultural relativism without common capacities cannot explain recurring lullaby, dance, or coordination functions. The evidence supports shared foundations with learned representational systems. (Jacoby et al., 2020, 2024; Athanasopoulos et al., 2021)

Key distinctions: association vs. causation • mechanism vs. metaphor • group average vs. individual response

18. Opportunity, Class, and the Myth of Pure Talent

Expertise is expensive in time even when lessons are free. Families provide transportation, instruments, quiet practice space, schedule flexibility, internet access, encouragement, and protection from competing demands. School districts differ in staffing and ensembles. Disability access, audition culture, fees, and neighborhood safety affect participation. When opportunity is unequal, observed achievement cannot be read directly as biological potential.

Selection operates at every stage. Teachers may invest more in children who already resemble their idea of talent. Early access produces early fluency, which is then mistaken for innate superiority. Anxiety, stereotype, and unfamiliarity can depress performance in auditions. Genres learned outside institutions may be undervalued because skill is not encoded in notation or certificates. A fair assessment asks what a learner has had the chance to practice.

Equity does not require pretending that all individuals will achieve identical outcomes. It requires withholding deterministic labels, widening entry points, valuing multiple musical roles, and providing enough exposure for preferences and capacities to emerge. Genetic evidence strengthens rather than weakens this case: when people differ in how they respond to environments, opportunity must be flexible and sustained. Talent is not pure biology; it is recognized performance produced within an opportunity structure. (Sala & Gobet, 2020; Wesseldijk & Ullén, 2023)

Key distinctions: association vs. causation • mechanism vs. metaphor • group average vs. individual response

19. The Algorithmic Soundscape

Streaming systems now mediate discovery at enormous scale. Collaborative filtering learns from similar users; content models learn from audio and metadata; ranking systems optimize engagement under platform goals. Personalization can uncover niche music and reduce search costs. It can also amplify popularity, reproduce biased data, and make exposure dependent on opaque commercial choices.

Fairness has several stakeholders. Users want relevant and sometimes diverse recommendations; artists need exposure and compensation; platforms seek retention; cultures need more than the survival of already dominant catalogs. A system can improve average satisfaction while underserving beyond-mainstream

listeners or repeatedly favoring established artists. There is no single fairness metric that resolves these interests.

Algorithms become part of development when adolescents treat recommendations as mentors. Repetition shapes familiarity and preference, while skips and short previews shape production incentives. Generative AI further separates musical surface from human biography, raising questions about consent, attribution, labor, and cultural training data. The key issue is not whether technology ruins authentic taste. Taste has always been socially mediated. The issue is who designs the mediation, what it optimizes, and whether listeners and creators can contest it. (Dinnissen & Bauer, 2022; Vaizman et al., 2023; Mokoena, 2025)

Evidence posture: Emerging confidence. Interpretation depends on the measured component, population, comparator, and duration; broad slogans are less defensible than specific claims.

Key distinctions: association vs. causation • mechanism vs. metaphor • group average vs. individual response

20. Music as Treatment

Music-based care ranges from listening to live relational therapy, singing, songwriting, rhythmic cueing, instrument practice, and technology-assisted rehabilitation. Credentialed music therapy uses assessment, goals, and an ongoing therapeutic relationship; a hospital playlist is not the same intervention. Reviews that collapse these forms can produce an average that describes none of them well.

Evidence is most persuasive when the outcome matches the mechanism: rhythmic cueing for movement, singing for respiratory-vocal or language practice, preferred music for short-term anxiety or distress, and relational music-making for engagement. Systematic reviews report benefits in some dementia, stroke, Parkinson, pain, anxiety, and mood outcomes, but effect sizes and certainty vary. Blinding is difficult, samples are often small, and usual-care controls do not match attention or expectancy.

Clinical value need not mean cure. A temporary reduction in pain, a calmer procedure, more coordinated steps, or a moment of communication can matter. But music should not replace indicated medical treatment, and no intervention is free of burden or adverse response. Preference, hearing safety, trauma history, culture, fatigue, and consent must guide use. The scientifically honest promise is a targeted adjunct with condition-specific evidence—not a universal medicine. (van der Steen et al., 2017; Janzen et al., 2022; Ramaswamy & Desai, 2024)

Evidence posture: Moderate confidence. Interpretation depends on the measured component, population, comparator, and duration; broad slogans are less defensible than specific claims.

Key distinctions: credentialed therapy vs. generic listening • meaningful symptom relief vs. cure

21. When Music Harms or Fails

The positive cultural status of music creates a blind spot. Loud listening can cause noise-induced hearing loss and tinnitus. A 2022 global analysis estimated that between roughly 0.67 and 1.35 billion young people could be at risk from unsafe

personal listening or loud entertainment venues. Risk depends on level, duration, recovery, and individual susceptibility; enjoyment does not protect the cochlea.

Music can also distract, overstimulate, trigger traumatic memory, intensify rumination, or interfere with sleep. Earworms are common, but bedtime listening has been associated in some research with nocturnal involuntary musical imagery and poorer sleep. In care settings, unwanted music can remove control from people already experiencing vulnerability. A song meaningful to staff may be irritating or frightening to a patient.

Failure must be counted honestly. Some interventions show no improvement over active controls, and broad cognitive transfer often shrinks with rigorous design. Publication bias favors positive findings; flexible outcome selection allows a trial to emphasize whichever measure improved. Adverse effects are underreported. Responsible practice begins with the possibility that silence, another activity, or standard therapy is better. (Dillard et al., 2022; Pienkowski, 2021; Scullin et al., 2021)

Evidence posture: High confidence. Interpretation depends on the measured component, population, comparator, and duration; broad slogans are less defensible than specific claims.

Key distinctions: enjoyment vs. safety • ordinary earworms vs. hallucination or obsession

22. The Strongest Counterarguments

A skeptic can explain much of the literature without granting broad causal power to music. Families who choose lessons differ before training. Skilled people practice because they are skilled. Researchers compare musicians with nonmusicians after years of self-selection. Small samples, multiple outcomes, and publication bias inflate effects. Brain differences are interpreted as training even when preexisting differences could have influenced selection.

Clinical studies face parallel problems. Participants know whether they received music; therapists cannot be blinded; preference and expectancy influence subjective outcomes; usual-care controls receive less attention; and interventions vary too much to pool. Short-term anxiety or pain changes may not persist. In dementia, meaningful engagement can be mistaken for cognitive recovery. In education, near transfer can be advertised as generalized intelligence.

These objections do not erase all effects. They grade them. Fetal memory for repeated sound, learning of musical grammar, improvement in practiced musical skills, auditory-motor entrainment, and the risk of hearing damage are well supported. Broader cognitive enhancement, durable disease modification, and individual genetic prediction are much weaker. The project's conclusion survives skepticism by becoming more specific: music matters through identifiable mechanisms under identifiable conditions, not as a universal causal force. (Sala & Gobet, 2020; Mosing et al., 2014; van der Steen et al., 2017)

Key distinctions: association vs. causation • mechanism vs. metaphor • group average vs. individual response

23. What the Evidence Allows Us to Say

High-confidence conclusions include that humans develop sensitivity to patterned sound early; prenatal exposure can produce memory for specific auditory material; musical component traits vary partly for genetic reasons; culture shapes expectation and emotional interpretation; training improves trained skills; synchronization links auditory and motor systems; preferred music can alter short-term emotion and arousal; and unsafe sound exposure can damage hearing.

Moderate conclusions include that responsive caregiver singing supports co-regulation, some structured training benefits executive or language-related skills, rhythmic interventions improve selected motor outcomes, and music-based care can improve certain mood, distress, behavioral, or quality-of-life outcomes. Confidence varies by population, comparator, dosage, and follow-up. These findings should be described with outcome-specific language.

Emerging or disputed conclusions include precise molecular prediction of musical ability, large far-transfer effects on intelligence or achievement, durable prenatal enhancement, broad disease modification, and universal emotional meanings for Western harmony. The absence of certainty is not evidence of no effect; it is a boundary on communication. A mature account of music can be powerful without being inflated.

Evidence posture: Synthesis confidence. Interpretation depends on the measured component, population, comparator, and duration; broad slogans are less defensible than specific claims.

Key distinctions: association vs. causation • mechanism vs. metaphor • group average vs. individual response

24. Implications and Research Agenda

Families can sing, listen, and make music without turning childhood or pregnancy into optimization. Schools should defend music as education in its own right, widen access, and evaluate programs on musical learning, belonging, participation, and specific transfer rather than promises of generalized intelligence. Teachers should use multiple entry points and avoid treating early performance as destiny.

Clinicians should define the intervention, target, comparator, and meaningful outcome; screen for preference, trauma, sensory sensitivity, and hearing risk; and distinguish supportive listening from credentialed therapy. Researchers need larger preregistered samples, active controls, longer follow-up, shared outcome sets, adverse-event reporting, diverse cultural participation, and designs that model genetic selection into training.

Technology platforms should expose recommendation controls, measure diversity and stakeholder fairness, allow users to reset or challenge profiles, and disclose AI-generated material. Genetic researchers should resist direct-to-consumer talent scoring and expand ancestry diversity before generalization. Across domains, the next research generation should replace the question 'Does music work?' with

'Which musical activity, for whom, compared with what, through which mechanism, for how long, and at what cost or risk?'

Key distinctions: association vs. causation • mechanism vs. metaphor • group average vs. individual response

Conclusion: Inheritance Is Not Destiny

The music within a person is not a sealed object waiting to be discovered. It is a capacity repeatedly constructed. Genes contribute to variation in component abilities and dispositions; bodies and brains learn from patterned sound; caregivers turn timing into relationship; cultures turn sound into grammar and identity; practice changes perception and movement; technology reshapes exposure; memory turns songs into personal history.

This layered explanation is more demanding than either romantic talent or simple environmentalism. It refuses to call privilege a gift, practice a guarantee, heritability a fate, neural activation a benefit, or a meaningful clinical moment a cure. It also refuses the opposite cynicism that music is merely entertainment because some claims are overstated. Specific effects remain real when broad slogans are removed.

Music matters because it coordinates prediction, body, emotion, memory, and belonging in ways that can be measured but never reduced to one measurement. Its power is conditional, personal, cultural, and sometimes harmful. The most accurate final answer is therefore neither that music is passed down nor that it is taught. What passes between generations is a changing system of biological

possibilities, relationships, practices, technologies, and meanings. Inheritance opens paths; development walks them; culture names where they lead.

Key distinctions: association vs. causation • mechanism vs. metaphor • group average vs. individual response

Evidence Map

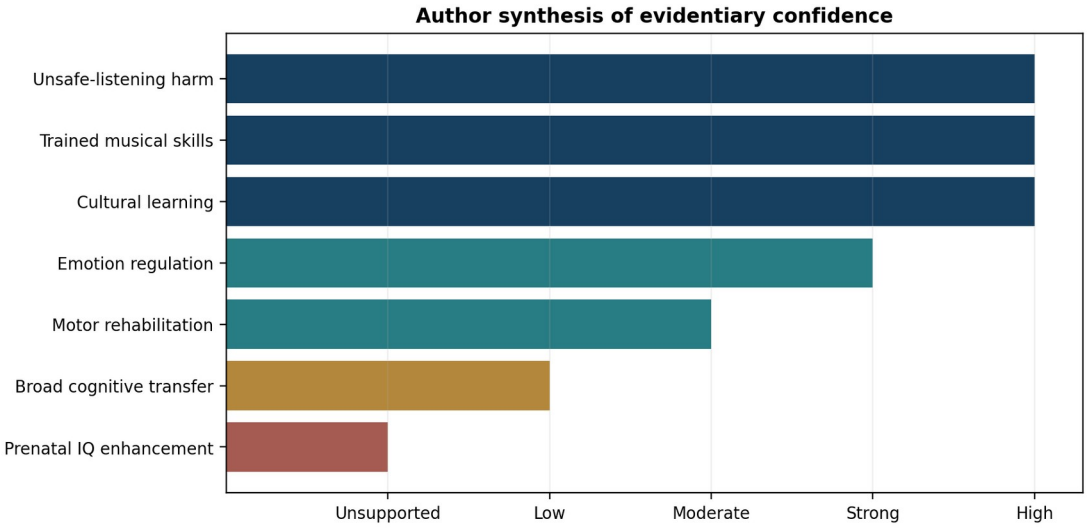

Figure 2. Author synthesis of evidentiary confidence. Ratings are interpretive summaries, not pooled estimates or formal clinical grades.

Domain	Confidence	Boundary
Genetic influence on component traits	Moderate-High	Twin and emerging genomic evidence; no individual destiny.
Single music gene	Unsupported	Complex, polygenic, multi-component phenotype.
Prenatal sound memory	Moderate	Recognition and physiological response; limited long-term follow-up.
Prenatal music raises intelligence	Unsupported	Short-term neonatal measures do not establish durable enhancement.
Training improves trained skills	High	Direct learning effect; magnitude

Domain	Confidence	Boundary
		varies.
Training broadly raises IQ/achievement	Mixed-Low	Effects shrink with active controls and better design.
Culture shapes musical expectation	High	Cross-cultural commonality and variation both documented.
Music regulates emotion	Moderate-High	Strong everyday function; response is individualized and contextual.
Rhythm supports selected motor rehabilitation	Moderate	Mechanism-specific benefits; functional transfer varies.
Music modifies neurodegenerative disease	Unsupported	Symptom and engagement benefits are not disease reversal.
Unsafe listening risks hearing	High	Level-duration exposure is a major preventable risk.
Algorithms shape exposure and fairness	Moderate	Clear mediation and bias concerns; long-term developmental effects emerging.

Representative Study Evidence Table

Study	Design/sample	Principal result	Primary limitation
Mosing et al., 2014	Twin/co-twin; 10,500 Swedish twins	Practice heritability 40%-70%; practice-ability association largely genetic.	Retrospective practice; one population; practice still teaches practiced skills.
Sala & Gobet, 2020	Meta-analysis; 38 studies, 118 effects, n=3,085	Overall nonmusic transfer d=0.16; effect declined with design quality.	Heterogeneous training/outcomes; debated by later syntheses.
Cai & Kang, 2025	Three-level meta-analysis; 46 reports, 192 effects, n=3,530	Executive-function estimate g=0.35, 95% CI [0.25, 0.45].	Cultural and intervention moderators; design variation.
Movalled et al., 2023	Systematic review of prenatal sound research	Stimulus-specific fetal/newborn memory	Heterogeneous exposure; limited long-term follow-

Study	Design/sample	Principal result	Primary limitation
		supported.	up.
Dillard et al., 2022	Systematic review/meta-analysis; 33 studies, >19,000	Personal-device unsafe exposure 23.81%, 95% CI [18.99, 29.42]; venue model 48.20%.	Venue estimate had limited certainty; exposure is not diagnosed loss.
van der Steen et al., 2018	Cochrane dementia review	Cognition SMD 0.15, 95% CI [-0.06, 0.36]; 7 studies, n=350.	Intervention heterogeneity; limited long-term evidence.
Jacoby et al., 2024	Large cross-cultural rhythm study	Shared constraints plus substantial cultural variation in rhythm priors.	No task or sample represents every musical culture.
Martínez-Molina et al., 2016	Neurobehavioral musical-anhedonia study	Selective disruption of auditory-reward interaction supported.	Specialized samples; not a treatment study.
Lense et al., 2022	Infant-directed singing experiment	Singing rhythm predicted infant social visual attention.	Short-term laboratory behavior; not later attachment.
Janzen et al., 2022	Motor-rehabilitation review	Mechanism-specific support for selected gait and motor outcomes.	Protocols and functional transfer vary by condition.

Note. Values are reproduced from cited publications or indexed abstracts. This representative table is designed for auditability and is not an exhaustive extraction.

Recommendations by Audience

Audience	Recommendation
Families	Use music for relationship, play, culture, and enjoyment. Avoid prenatal or childhood optimization promises. Protect hearing and respect preference.
Schools	Provide broad access; value musical learning itself; use multiple entry points; do not sort children by early tests or genetic claims.

Audience	Recommendation
Clinicians	Name the intervention and target; screen for hearing, trauma, sensory needs, and preference; use active comparisons and meaningful outcomes.
Researchers	Preregister, use active controls, follow participants longer, report null and adverse outcomes, diversify cultures and ancestry, and model selection.
Platforms	Offer meaningful recommendation controls, audit popularity and representation bias, label AI-generated content, and support creator transparency.
Policymakers	Fund arts access and hearing prevention without requiring exaggerated cognitive or medical claims.
Readers	Ask: which activity, for whom, compared with what, measured how, for how long, and with what risk?

Appendix A: Claim Audit

Public claim	Assessment	Correction
Musical ability runs in families.	Partly supported	Genes, culture, access, identity, and opportunity are confounded.
Practice makes anyone an expert.	Overstated	Practice matters, but selection, quality, health, opportunity, and predisposition affect response.
Absolute pitch proves genetic genius.	Unsupported framing	It depends strongly on early exposure and is neither necessary nor sufficient for musicianship.
Babies remember prenatal music.	Supported narrowly	Memory for repeated sound is not proof of later intelligence.
Music lessons make children smarter.	Mixed/overstated	Near transfer is more credible; broad effects shrink in better-controlled studies.
Sad music causes sadness.	Too simple	Perceived emotion, felt emotion, pleasure, nostalgia, empathy, and rumination differ.

Public claim	Assessment	Correction
Music is a universal language.	Metaphor only	Some cues travel; grammar and meaning are culturally learned.
Music therapy treats dementia.	Supported for selected symptoms	It may aid engagement or mood; it does not reverse neurodegeneration.
Listening loudly is safe if it feels comfortable.	False	Risk depends on sound level and duration, not discomfort alone.
Algorithms merely reflect taste.	False/incomplete	They also shape exposure, popularity, and future feedback data.
A brain change proves benefit.	False	Plasticity or activation requires behavioral and functional interpretation.
No universal effect means music does nothing.	False	Conditional, mechanism-specific effects can be meaningful.

Appendix B: Study-Design Decoder

Design	Strength	Main caution
Twin/family	Separates sources of population variation	Equal-environment assumptions; generalizability; measurement.
Genome-wide association	Finds distributed molecular associations	Very small effects; ancestry bias; prediction limits.
Cross-sectional musician comparison	Describes group differences	Cannot separate training from selection.
Longitudinal cohort	Tracks developmental order	Confounding and attrition remain.
Randomized active-control trial	Best test of intervention causality	Adherence, blinding, dose, and external validity.
Meta-analysis	Synthesizes effect sizes	Inherits bias and heterogeneity of included studies.
Neuroimaging	Tests mechanisms and networks	Reverse inference; small samples; brain difference is not benefit.

Design	Strength	Main caution
Cross-cultural experiment	Tests commonality and learning	Translation, construct validity, globalization, ecological validity.
Clinical case study	Shows possibility and lived detail	Cannot establish frequency or average effectiveness.

Appendix C: Glossary

Term	Working definition
Absolute pitch	Ability to identify or produce a pitch without an external reference; influenced by early exposure and language as well as individual differences.
Active control	A comparison group receiving an activity matched for time, attention, expectation, or social contact.
Amusia	A selective difficulty with aspects of music perception or production that cannot be explained simply by hearing loss or low intelligence.
Assortative mating	Nonrandom partnering among people with similar traits, interests, education, or environments; relevant to family resemblance.
Auditory-motor coupling	Functional interaction between hearing and movement systems used in beat tracking, performance, speech, and rehabilitation.
Candidate gene study	A study testing selected genes thought to relate to a trait; historically vulnerable to small samples and nonreplication.
Causal inference	Reasoning about whether changing an exposure changes an outcome, rather than merely observing that they occur together.
Congenital amusia	Developmental difficulty processing musical pitch or structure without acquired brain injury.
Confounding	A third factor associated with both exposure and outcome that can create or distort an apparent effect.
Entrainment	Alignment of internal timing, attention, or movement

Term	Working definition
	with an external rhythm.
Executive function	Control processes including working memory, inhibition, and cognitive flexibility.
Far transfer	Improvement in a task or domain substantially different from the trained activity.
Gene-environment correlation	Processes through which genetic differences become associated with different environments people receive, evoke, or select.
Gene-environment interaction	A situation in which the effect of an environment depends on biological differences, or vice versa.
Genome-wide association study	A scan across many genetic variants to identify statistical associations with a measured trait.
Heritability	The proportion of observed variation in a population statistically associated with genetic variation under specified conditions.
Involuntary musical imagery	Music experienced in the mind without deliberate initiation; ordinary examples are called earworms.
Musical anhedonia	Unusually low reward or pleasure from music despite otherwise typical perception and reward response.
Musicality	A broad family of capacities for perceiving, producing, learning, enjoying, and socially using music.
Near transfer	Improvement in an untrained task that closely overlaps the trained skills or mechanisms.
Neuroplasticity	Change in neural structure or function with experience, learning, injury, or adaptation; not inherently beneficial.
Polygenic trait	A trait influenced by many genetic variants, usually with each contributing a very small effect.
Preregistration	Publicly specifying hypotheses, outcomes, and analyses before examining results, reducing undisclosed flexibility.
Predictive processing	A framework in which perception depends partly on expectations updated by incoming sensory information.
Publication bias	Greater likelihood that positive or striking results are published than null or contradictory findings.

Term	Working definition
Rhythmic auditory stimulation	Use of external rhythmic cues to support timing and movement, commonly studied in gait rehabilitation.
Sensitive period	A developmental interval when particular experience may have unusually strong or efficient effects; not necessarily an absolute deadline.
Specific musical anhedonia	Low musical pleasure that is relatively selective rather than part of a general inability to experience reward.
Synchronization	Coordination of actions or physiological timing between people or with a rhythmic signal.
Transfer effect	Change in performance outside the exact activity practiced.
Western-centric measurement	Assessment built around Western concepts such as equal temperament, major-minor harmony, notation, or formal lessons and treated as culturally neutral.

Appendix D: Priority Research Questions

Domain	Priority question
Genetics	Can well-powered studies across diverse ancestry groups replicate associations for specific pitch, rhythm, reward, and practice phenotypes?
Measurement	Can a cross-cultural musicality battery preserve local meaning while permitting valid comparison?
Development	Which prenatal or infant auditory effects persist beyond recognition, and what caregiving pathway explains them?
Training	Which learner, teacher, dose, and task features predict near transfer under active-control conditions?
Opportunity	How do cost, school access, disability, neighborhood, and family time alter both participation and apparent heritability?
Emotion	When does mood-congruent listening regulate emotion, and when does it reinforce rumination?

Domain	Priority question
Social bonding	How long do synchrony-related affiliation effects last, and can they reduce rather than intensify intergroup division?
Aging	Which music-based outcomes are durable and meaningful to people with dementia and their caregivers?
Rehabilitation	Do laboratory gains from rhythmic cueing reduce falls, disability, or caregiver burden outside treatment?
Adverse effects	How often do music interventions trigger distress, fatigue, sensory overload, or unwanted memories?
Hearing	Which platform and venue interventions most effectively reduce cumulative unsafe exposure without reducing access?
Algorithms	Do recommender controls increase discovery diversity and artist fairness without reducing user satisfaction?
Generative AI	How should consent, attribution, training data, cultural ownership, and creator compensation be measured and governed?
Replication	Which high-profile music-and-brain effects survive multisite preregistered replication?
Communication	Which wording best prevents readers from interpreting heritability as destiny or symptom relief as cure?

Minimum Standards for the Next Generation

- State the musical activity precisely rather than using music as a single exposure.
- Use active comparison conditions when attention and expectancy could explain outcomes.
- Measure baseline aptitude, resources, prior exposure, hearing, and motivation.
- Predefine primary outcomes and report null, negative, and adverse results.
- Include follow-up long enough to distinguish immediate state change from durable learning.

- Partner with communities when constructs or musical categories may not translate.
- Share materials and analytic code where privacy and cultural ownership permit.
- Report effect magnitude and practical meaning, not statistical significance alone.

Appendix E: Practical Interpretation Checklist

Use this checklist when reading a headline, school proposal, genetic report, brain image, wellness claim, or clinical study about music.

#	Question
1	What exactly was the musical exposure: listening, lessons, singing, movement, therapy, rhythmic cueing, or performance?
2	Was the outcome a practiced skill, a laboratory proxy, a symptom rating, or a durable daily-life change?
3	Were participants randomly assigned, or did they select the activity?
4	Did the comparison group receive equal attention, expectation, time, movement, and social contact?
5	Were baseline ability, family resources, hearing, culture, and prior training measured?
6	Was the sample large and diverse enough for the conclusion?
7	Were many outcomes tested but only one positive result highlighted?
8	How large was the effect, and did it persist after the intervention ended?
9	Is a group association being converted into a prediction about one person?
10	Is a brain difference being treated as proof of benefit?
11	Is short-term comfort being described as treatment or

#	Question
	cure?
12	Were preference, consent, hearing safety, trauma, and adverse effects considered?
13	Would the conclusion still sound impressive if written with accurate causal language?
14	Who benefits financially or institutionally from the claim?
15	What finding would change the author's conclusion?

Fast rule The broader the claim, the stronger the design must be. Specific mechanism-and-outcome claims are usually more credible than statements that music changes the brain, raises intelligence, or heals.

Appendix F: Public Communication Guide

Avoid	Prefer
Music is genetic.	Several component music traits show genetic influence in studied populations.
Talent is inherited.	Predispositions, opportunities, training, and identity interact across development.
Music makes children smarter.	Training improves musical skills and may produce modest transfer in selected domains.
Babies learn music in the womb.	Repeated prenatal sounds can produce newborn memory and recognition.
Music rewires the brain.	Learning is associated with experience-dependent neural change whose functional meaning must be tested.
Music therapy cures dementia.	Music-based care may improve selected behavioral, emotional, or engagement outcomes.
Music is universally healing.	Response depends on intervention, person, preference, context, goal, and risk.

Avoid	Prefer
The algorithm knows your taste.	The system predicts engagement from data while also shaping future exposure.
This genre causes bad behavior.	Preference and behavior share personal and social causes; direct effects are conditional and often small.
No effect was found, so music does not matter.	This design did not demonstrate the specified outcome under the tested conditions.

Confidence Language

Phrase	Use when
Evidence supports	Several credible and reasonably consistent studies directly address the claim.
Evidence suggests	The direction is plausible but limitations or heterogeneity remain.
Evidence is mixed	Credible positive and null findings depend on design, measure, or population.
Evidence is insufficient	The available studies cannot justify a conclusion.
Evidence does not support	The specific popular claim exceeds or conflicts with credible findings.

References

Athanasopoulos, G., et al. (2021). Harmonic organisation conveys both universal and culture-specific cues for emotion. PLOS ONE, 16, e0245864. https://pmc.ncbi.nlm.nih.gov/articles/PMC7806179/

Cai, Y., & Kang, D. (2025). Boosting executive function in children aged 3-12 through musical training: A three-level meta-analysis. Frontiers in Psychology. https://pmc.ncbi.nlm.nih.gov/articles/PMC12446045/

Chen, L., et al. (2023). Influence of music on the hearing and mental health of adolescents and countermeasures. Frontiers in Public Health. https://pmc.ncbi.nlm.nih.gov/articles/PMC10434992/

Chong, H. J., et al. (2024). Scoping review on the use of music for emotion regulation. Behavioral Sciences. https://pmc.ncbi.nlm.nih.gov/articles/PMC11428991/

Chorna, O., et al. (2019). Neuroprocessing mechanisms of music during fetal and neonatal development. Frontiers in Psychology. https://pmc.ncbi.nlm.nih.gov/articles/PMC6446122/

Dillard, L. K., et al. (2022). Prevalence and global estimates of unsafe listening practices in adolescents and young adults. BMJ Global Health, 7, e010501. https://pmc.ncbi.nlm.nih.gov/articles/PMC9723884/

Dinnissen, K., & Bauer, C. (2022). Fairness in music recommender systems: A stakeholder-centered mini review. Frontiers in Big Data, 5, 913608. https://pmc.ncbi.nlm.nih.gov/articles/PMC9353048/

Gingras, B., et al. (2015). Defining the biological bases of individual differences in musicality. Philosophical Transactions of the Royal Society B, 370, 20140092. https://pubmed.ncbi.nlm.nih.gov/25646515/

Gordon, R. L., et al. (2015). Does music training enhance literacy skills? A meta-analysis. Frontiers in Psychology, 6, 1777. https://pmc.ncbi.nlm.nih.gov/articles/PMC4664655/

Jacoby, N., et al. (2020). Cross-cultural work in music cognition: Challenges, insights, and recommendations. Music Perception, 37, 185-195. https://pmc.ncbi.nlm.nih.gov/articles/PMC10019032/

Jacoby, N., et al. (2024). Commonality and variation in mental representations of music revealed by a cross-cultural comparison of rhythm priors. Nature Human Behaviour. https://pmc.ncbi.nlm.nih.gov/articles/PMC11132990/

Janzen, T. B., et al. (2022). Rhythm and music-based interventions in motor rehabilitation. Frontiers in Human Neuroscience, 15, 789467. https://pmc.ncbi.nlm.nih.gov/articles/PMC8801707/

Lense, M. D., et al. (2022). The music of infant-directed singing entrains infants' social visual behavior. Proceedings of the National Academy of Sciences, 119, e2116967119. https://pmc.ncbi.nlm.nih.gov/articles/PMC9659341/

Liikkanen, L. A., & Jakubowski, K. (2020). Involuntary musical imagery as a component of ordinary music cognition. Psychonomic Bulletin & Review, 27, 1195-1217. https://pmc.ncbi.nlm.nih.gov/articles/PMC7704448/

Loui, P., et al. (2017). White matter correlates of musical anhedonia. Social Cognitive and Affective Neuroscience, 12, 894-900. https://pmc.ncbi.nlm.nih.gov/articles/PMC5622186/

Martínez-Molina, N., et al. (2016). Neural correlates of specific musical anhedonia. Proceedings of the National Academy of Sciences, 113, E7337-E7345. https://pmc.ncbi.nlm.nih.gov/articles/PMC5135354/

Mokoena, N. (2025). An analysis of artificial intelligence automation in digital music. Humanities and Social Sciences Communications. https://pmc.ncbi.nlm.nih.gov/articles/PMC11774895/

Mosing, M. A., et al. (2014). Practice does not make perfect: No causal effect of music practice on music ability. Psychological Science, 25, 1795-1803. https://pubmed.ncbi.nlm.nih.gov/25079217/

Movalled, K., et al. (2023). The impact of sound stimulations during pregnancy on fetal learning: A systematic review. BMC Pediatrics, 23, 160. https://pmc.ncbi.nlm.nih.gov/articles/PMC10116668/

Nguyen, T., et al. (2023). Early social communication through music: State of the art and future perspectives. Developmental Cognitive Neuroscience, 63, 101279. https://pmc.ncbi.nlm.nih.gov/articles/PMC10407289/

Pienkowski, M. (2021). Loud music and leisure noise is a common cause of chronic hearing loss, tinnitus and hyperacusis. International Journal of Environmental Research and Public Health, 18, 4236. https://pmc.ncbi.nlm.nih.gov/articles/PMC8073416/

Raglio, A., et al. (2015). Effects of music and music therapy on mood in neurological patients. World Journal of Psychiatry, 5, 68-78. https://pmc.ncbi.nlm.nih.gov/articles/PMC4369551/

Ramaswamy, M., & Desai, G. (2024). Therapeutic use of music in neurological disorders. Annals of Indian Academy of Neurology. https://pmc.ncbi.nlm.nih.gov/articles/PMC11365335/

Reybrouck, M., et al. (2022). Musical enjoyment and reward: From hedonic pleasure to eudaimonic listening. Behavioral Sciences, 12, 154. https://pmc.ncbi.nlm.nih.gov/articles/PMC9137732/

Sachs, M. E., et al. (2015). The pleasures of sad music: A systematic review. Frontiers in Human Neuroscience, 9, 404. https://pmc.ncbi.nlm.nih.gov/articles/PMC4513245/

Sala, G., & Gobet, F. (2020). Cognitive and academic benefits of music training with children: A multilevel meta-analysis. Memory & Cognition, 48, 1429-1441. https://pmc.ncbi.nlm.nih.gov/articles/PMC7683441/

Saarikallio, S. H., et al. (2020). Music listening for supporting adolescents' sense of agency in daily life. Frontiers in Psychology, 10, 2911. https://pmc.ncbi.nlm.nih.gov/articles/PMC6960221/

Scullin, M. K., et al. (2021). Bedtime music, involuntary musical imagery, and sleep. Psychological Science, 32, 985-997. https://pmc.ncbi.nlm.nih.gov/articles/PMC8641138/

Singh, M., & Mehr, S. A. (2023). Universality, domain-specificity, and development of psychological responses to music. Nature Reviews Psychology. https://pmc.ncbi.nlm.nih.gov/articles/PMC10745197/

Tarr, B., et al. (2014). Music and social bonding: Self-other merging and neurohormonal mechanisms. Frontiers in Psychology, 5, 1096. https://pmc.ncbi.nlm.nih.gov/articles/PMC4179700/

Trehub, S. E., et al. (2015). Cross-cultural perspectives on music and musicality. Philosophical Transactions of the Royal Society B, 370, 20140096. https://pmc.ncbi.nlm.nih.gov/articles/PMC4321137/

Ullal-Gupta, S., et al. (2013). Linking prenatal experience to the emerging musical mind. Frontiers in Systems Neuroscience, 7, 48. https://pmc.ncbi.nlm.nih.gov/articles/PMC3759965/

van der Steen, J. T., et al. (2017). Music-based therapeutic interventions for people with dementia. Cochrane Database of Systematic Reviews. https://pmc.ncbi.nlm.nih.gov/articles/PMC6481517/

Vaizman, T., et al. (2023). Music mentors of the streaming era: From algorithms to influencers. Frontiers in Psychology, 14, 1044693. https://pmc.ncbi.nlm.nih.gov/articles/PMC10078019/

Wan, C. Y., & Schlaug, G. (2010). Music making as a tool for promoting brain plasticity across the life span. Neuroscientist, 16, 566-577. https://pmc.ncbi.nlm.nih.gov/articles/PMC2996135/

Wang, L., & Zhang, J. D. (2022). Music aptitude, training, and cognitive transfer: A mini-review. Frontiers in Psychology, 13, 873596. https://pmc.ncbi.nlm.nih.gov/articles/PMC9277581/

Wesseldijk, L. W., & Ullén, F. (2023). Music and genetics. Neuroscience & Biobehavioral Reviews, 150, 105199. https://pubmed.ncbi.nlm.nih.gov/37400010/

Xu, C., et al. (2022). Potential benefits of music therapy on stroke rehabilitation. Oxidative Medicine and Cellular Longevity, 2022, 9386095. https://pmc.ncbi.nlm.nih.gov/articles/PMC9217607/

Declarations

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Conflicts of interest

The author declares no financial or institutional conflict of interest related to the conclusions presented.

Author contribution

The anonymous author conceived the project, defined its public-facing questions, and approved its scope. Research organization, drafting assistance, source mapping, formatting, and figure production were completed with OpenAI language-model assistance under author direction.

AI-assistance disclosure

Generative AI assisted with literature organization, synthesis drafting, editing, reference formatting, and original figure construction. AI output is not peer review. The paper is explicitly offered for independent source checking, methodological critique, and substantive review before any claim of external validation.

Data and materials availability

No new participant data were collected. The quantitative values shown are drawn from cited publications. Stable links are provided in the reference list; the author-synthesis confidence ratings can be reconstructed from the Evidence Map and Representative Study Evidence Table.

Ethics statement

This narrative review used publicly available scholarly literature and involved no human-subject recruitment, intervention, or identifiable private data.

Project Note

The Music Within is part of the Beyond the Numbers Research Series, an independent project examining how biology, environment, culture, and social conditions shape human behavior and development.

The Music Within was developed as an independent, public-facing research synthesis. Its purpose is educational. It does not provide individualized genetic, developmental, educational, psychological, or medical diagnosis or treatment. Clinical decisions should be made with qualified professionals using current condition-specific guidance.

Publication standard Claims are deliberately narrower than common promotional language. Future editions should update the evidence map as larger preregistered, cross-cultural, genomic, and clinical studies appear.